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DETECTION OF LOW-CONTRAST MOVING TARGETS

John P. Mazz
Regina W. Kistner
William T. Pibil

U.S. Army Materiel Systems Analysis Activity
392 Hopkins Road
Aberdeen Proving Ground, Maryland 21005-5071
The United States of America
E-mail: mazz@arl.mil

1. SUMMARY

The U.S. Army Materiel Systems Analysis Activity (USAMSAA) designed a perception experiment to assess the influence of target angular velocity on the detectability of low to moderate contrast targets. The Moving Target Experiment II (MTE II) was designed to be representative of search with the unaided eye. Target angular velocity, range, contrast, and background were varied. Targets with near-equal contrast at identical range and angular velocity yielded widely different probabilities of detection. However, within a specific background region, contrast had a significant impact. This localized impact of target contrast indicates that further improvements in search and target acquisition modeling requires the evaluation of scene-content's impact on target detection (i.e., what about the scene leads an observer to the vicinity of the target.) For low-contrast targets, scene content has even greater impact on detection.

The U.S. Army's standard methodology for representing search and target acquisition in combat models is the ACQUIRE model. Current implementations of ACQUIRE utilize the "two-thirds rule" to represent the detection of all moving targets regardless of angular velocity. The $n50$ for the detection of moving targets is simply $2/3$ of the $n50$ used to represent the detection of stationary targets. Results of the MTE II and other experiments indicate that the appropriate ratio of moving-to-stationary $n50$ decreases as a function of angular velocity. A ratio of $2/3$ equates to an angular velocity of 1 milli-radian/sec and a ratio of $1/3$ equates to an angular velocity of 3.3 milli-radians/sec.

Keywords: Detection, moving targets, search, target acquisition, false targets, $n50$, Johnson criteria, perception experiment, low contrast, ACQUIRE model

2. INTRODUCTION

The U.S. Army's standard methodology for modeling man-in-the-loop target acquisition performance is the ACQUIRE Model developed by the U.S. Army Communications and Electronics Command Research Development and Engineering Center's Night Vision and Electronic Sensors Directorate (NVESD).¹ ACQUIRE predicts the probability of detection (P_d) as a function of Minimum Resolvable Contrast (MRC); target size, range and contrast; and an observer task parameter called $n50$. The MRC provides the minimum contrast at which a specific spatial frequency (cycles per milli-radian) can be resolved by an observer. The $n50$ parameter (also known as the Johnson criterion) is defined as the number of cycles across the target (at the maximum resolvable spatial frequency) required for 50 percent of the observer population to detect the target. The Johnson criterion is also used to represent higher levels of

target discrimination such as recognition and identification; however, this effort is concerned only with detection.

In current implementations of ACQUIRE, the value of $n50$ for moving targets is set to two-thirds the value of $n50$ for detection of stationary targets. This two-thirds value was derived from results of the Moving Target Experiment I (MTE I)². Prior to MTE I, a $n50$ value of 0.5 was used to represent detection of moving targets.

Modeling the detection of moving targets with a single $n50$ value is rather simplistic. Under this approach, the angular velocity of the target is not taken into consideration. Slow moving targets are equally as detectable as fast moving targets. This approach may be adequate for most direct-fire battle scenarios; but for the assessment of the value of low-contrast in the scout mission, this approach is woefully inadequate.

Results of MTE I gave indications that, as expected, the $n50$ for moving targets decreases with increasing angular velocity. Unfortunately, since ground speed was the primary parameter representing velocity at each range, sample sizes with respect to angular velocity were small. MTE I was also limited to foveal detection, no search was involved. Since search is a significant aspect to most tactically realistic scenarios, MTE II was designed as a search experiment to collect statistically significant samples with respect to angular velocity. As a result of the MTE II experiment, we hope to further refine the $n50$ values used for moving targets.

The MTE II laboratory perception experiment was designed and analyzed by the U.S. Army Materiel Systems Analysis Activity (AMSAA) under the auspices of the Joint Technical Coordinating Group for Munitions Effectiveness (JTTCG/ME). The test was conducted by the U.S. Army Tank-Automotive and Armaments Command Research, Development and Engineering Center (TARDEC) at their Perception Laboratory in Warren, Michigan in 1998.

3. EXPERIMENT DESIGN

The experimental design consists of four primary parameters of interest: background, target size (simulated range), target contrast, and velocity. In all, 565 sequences were presented to each of the observers -- 80 percent with targets and 20 percent without targets. The 80 percent with targets consisted of a full-factorial experimental design of the four parameters. The primary purpose of the no-target trials was to discourage guessing by allowing the possibility of no target present. Furthermore, these no-target trials provide a means of quantifying an observer's willingness to guess.

3.1. Stimuli

The experimental stimuli were created from 35mm visual imagery taken during a field test exercise. This field exercise was conducted in a desert environment. Five images were chosen, each having different clutter and target contrast levels. These images are referred to as background images 4, 7, 12, 14, and 15. The target in each image was a side aspect military vehicle. All five images were manually adjusted to represent three conditions: stationary target, moving target, and no-target. The targets were separated from the background images and the backgrounds were “fixed” by substituting appropriate background in the area vacated by the target.

The .AVI movies were developed using commercial software to place the targets into the background scenes. The target starting and ending locations were calculated in order to represent the appropriate velocities for a specified range. The targets moved perpendicular to the observer’s line-of-sight in either the left or right direction. For the no-target image, no target was inserted into the scene.

Adobe Premiere software was used to create the motion sequences. Motion sequences were generated with lateral ground speeds dependent upon the simulated range. For the 750 meter range the four speeds were: 0, 2.5, 6.25 and 10 kilometers per hour (kph); while the 1500 meter range speeds were 0, 5, 12.5 and 20 kph; and the 3000 meter speeds were 0, 10, 25, and 40 kph. The four speeds at each range are represented by a single set of angular velocities of 0, 0.9, 2.3 and 3.7 milli-radians per second.

The targets started at either a left, central or right grid for a given range. The direction for the centrally located targets was determined randomly, while targets in locations on the right moved left and targets in locations on the left moved right. The target images were scaled to represent different ranges and then placed into the location in the background that corresponded to that range. The observer was seated 1.3 meters from a nominal 17 inch monitor and the target size was configured to represent three simulated ranges: 750, 1500 and 3000 meters. The software was also used to create stationary and motion sequences for targets with reduced contrast. The original image represented a high contrast target. The brightness level (for each of the Red, Green and Blue color spectra) of the target was decreased to represent lower contrasts. This process was conducted twice, yielding three contrast levels for each image.

The stimuli were constructed to represent an observer viewing the scene with the unaided eye. Each image sequence represented pure motion. There were no secondary environmental effects such as dust or motion-of-vegetation represented.

3.2. Conduct

The perception experiment was conducted by the TARDEC at their Perception Laboratory in Warren, Michigan. The computer display used was a Panasonic PanaSync/Pro P17 monitor. Observers were required to sit 1.3 meters from the screen to accurately simulate the ranges of interest. Each observer went through a training session. The training included written instructions read together with the test controller and an opportunity for the subject to go through the software and images, until the subject was thoroughly familiar with the images, targets, and test procedures.

A total of 22 observers participated in the perception experiment. The observers were recruited by a research firm and were reimbursed for their participation. Each subject

had some military experience, either active Army, Reserves or the National Guard. The subjects were between 25 and 45 years of age with normal/corrected 20/20 vision. Prior to participating in the experiment, each subject was screened for vision abnormalities using a Snellen chart and Ishihara color plate book. Each observer was presented with the entire set of 565 images. The order of presentation was randomized for each observer. Each image sequence lasted up to 9 seconds. Upon detecting the target, the observer clicked the computer mouse button and the target motion stopped. The observer was then required to use the mouse to click on the location of the target on the screen. The subjects were instructed that they could rest at any time during the test, by hitting the ‘O’ key or by telling the test controller to pause the test. The observer could then resume the test when ready.

The experiment lasted approximately 1 to 2 hours for each subject. No feedback was provided to the observers during the experiment; however, upon completion of the experiment, overall performance was provided to the observer upon request.

4. ANALYSIS OF RESULTS

The purpose of this experiment was to investigate the effects of target motion on the probability of target detection (Pd). Target detection was scored in the following manner. During the experimental trials, each observer was asked to locate the target he detected with crosshairs controlled by the computer mouse. A scoring box was created that was centered on the target and twice the length and width of the target. If the crosshair location given by the observer was within this box, the observer was scored to have a correct detection; otherwise, he was scored to have a false detection. [This scoring process was not perfect. It may score a false target as true since the scoring box is bigger than the target and a true target as false since the motion stopped after the observer indicated detection but before he indicated the target location.] Pd is estimated as the number of observers who detect divided the total number of observers (22).

The main parameters varied in this experiment were target angular velocity (0.0, 0.9, 2.3, and 3.7 milli-radians per second), simulated target range (750, 1500, and 3000 meters), and target contrast (original and attempted 50% and 75% reductions). Figure 1 shows the average Pd, collapsed over contrast, as a function of target angular velocity and range. As expected, Pd is strongly effected by both angular velocity and range. Pd increases with both increasing angular velocity and decreasing range. The corresponding ground speeds in kilometers per hour (kph) for the simulated lateral motion (perpendicular to the observer’s line-of-sight) are presented in Table 1. It is interesting to note that even with a ground speed as high as 40 kph, the Pd is still below 0.5 at 3km. Although increased angular velocities would likely increase this Pd, the practicality of exceeding 40 kph as a cross-country ground speed is unlikely. It should also be noted that as you transition from lateral to radial motion, angular velocity decreases.

Table 1 Simulated Ground Speeds in kph

Range \ Velocity	0.9 mr/sec	2.3 mr/sec	3.7 mr/sec
750 m	2.5	6.25	10
1500 m	5	12.5	20
3000 m	10	25	40

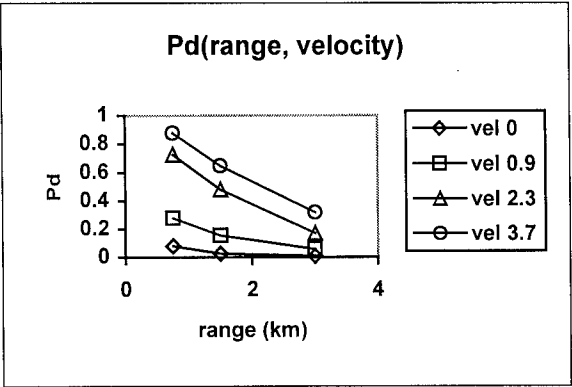


Figure 1 Probability of detection

In the analysis of target detection, it is important to investigate false detections. It provides insight to an observer's criterion (i.e., the trade-off between increased Pd and more false targets). Knowledge of false target performance is essential when comparing the results of different experiments as well as the results from different observers. Figure 2 shows the false target results of this experiment. The probability of selecting a false target on the 20% of trials containing no-targets was approximately 0.24. The four curves represent the probability of selecting a false target over a true target when the true target had specific values of range and angular velocity. Since these were single target trials, the observer could not detect both a true and a false target on the same trial; therefore, the sum of Pd and the probability of false target for a particular trial is always less than or equal to one. As range to the true target decreases or the angular velocity of the true target increases, the probability of false target decreases. Since the only motion in these scenes involved the target, it is safe to assume that all false targets were perceived as stationary by the observer. One anomaly in Figure 2 is that the average probability of false target (collapsed over target contrast) for the 0.9 mr/sec angular velocity is greater than that for the stationary trials. This difference is not statistically significant at the $\alpha=0.05$ level ($p\text{-value}=0.268$, one-sided Sign Test).

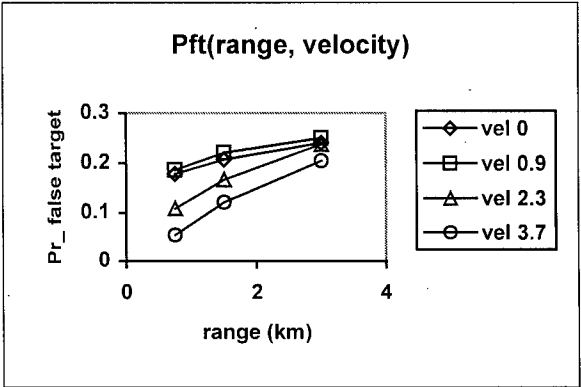


Figure 2 Probability of false target

The third main parameter varied in this experiment was target contrast – the original dark target and an attempt to reduce contrast by 50% and 75%. The chief measure of contrast used in this analysis was luminance (not color) contrast based on the area-weighted average of target and background image-pixel luminance-grayscale values. [In general, the area-weighted average contrast is a non-unique metric for real-world scenes. Its value varies depending on

what part or how much of the background is included in its calculation.] For simplicity, an average contrast value is used to represent the target contrast for the entire 9-second motion sequence. For the initial look at the effects of target contrast, the Pd was averaged within the following three contrast bins: 0.0 to 0.2, 0.2 to 0.4, and greater than 0.4. Pd's were placed into bins based on the absolute value of contrast. The majority of the contrasts were negative. Figure 3 shows Pd as a function of contrast bin, range, and angular velocity. Figure 3 is separated into three range regions; the x-axis going from an absolute contrast of 0.0 to 1.0 within each of these regions. Contrast seems to have a much milder effect on Pd than range or velocity. This is confirmed by the regression analysis presented in Table 2 where the inclusion of contrast explains only an additional 1% of the variation in Pd exhibited during this experiment.

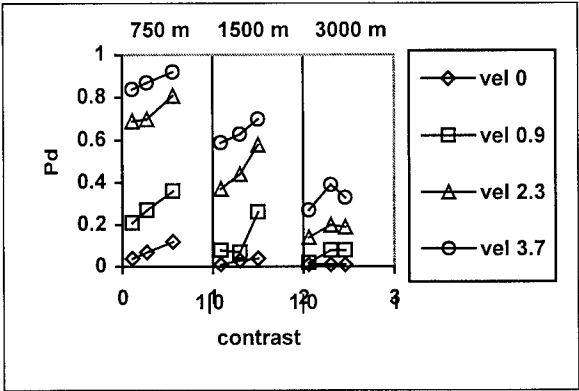


Figure 3 Pd versus range, velocity, and contrast

Table 2 Regression Analysis

Regression Variables	Percent Variation in Pd Accounted For
Angular Velocity only	48%
Range only	16%
Contrast only	3.6%
Velocity & Range	64%
Velocity & Range & Contrast	65%

One reason for the muted effect of target contrast is that the experiment involved search of a complex scene. Where an observer looks is determined by scene content and not by target contrast. However, once looking in the vicinity of the target, contrast has a greater impact as illustrated in Figure 4. Figure 4 shows the Pd results for the individual trials utilizing background image #14. The symbols in Figure 4 can be identified by the legend in Figure 3. Each vertical region represents one of nine potential target locations (listed at top of Figure 4). Locations 1, 2, and 3 are the top row (3000m); locations 4, 5, and 6 are the center row (1500m); and locations 7, 8, and 9 are the bottom row (750m) of the image. Locations 1, 4, and 7 are on the left; locations 2, 5, and 8 are in the center; and locations 3, 6, and 9 are on the right side of the image. In general, Figure 4 shows that as contrast increases so does Pd. However, comparing the 3 locations associated with a specific range, it can be seen that the Pd results are widely different. For example, although the highest contrast in locations 1, 2, and 3 is approximately 0.33, Pd's are much higher in location 1 than in locations 2 and 3. Similarly, the Pd's associated with the 0.9 mr/sec velocity in location 9 are much lower than the

Pd's in locations 7 and 8 even though contrast is nearly identical. One possible explanation for the above effect of identical contrasts yielding widely divergent Pd's is that the observers were less likely to look in the locations with lower Pd's. This localized impact of target contrast indicates that further improvements in search and target acquisition modeling requires the evaluation of scene-content's impact on target detection (i.e., what is it about the scene that leads an observer to the vicinity of the target.) For low-contrast targets, scene content has an even greater impact on detection.

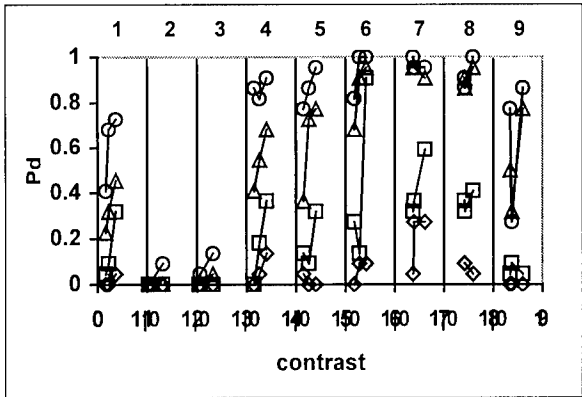


Figure 4 Pd results for background # 14

5. MODELING IMPLICATIONS

The U.S. Army's standard methodology for representing search and target acquisition in combat models is the ACQUIRE model¹. Current implementations of ACQUIRE utilize the "two-thirds rule" to represent the detection of all moving targets regardless of angular velocity. The n50 for the detection of moving targets is simply 2/3 of the n50 used to represent the detection of stationary targets. Admittedly, this is an oversimplification; however there has been little concrete data on which to base a more complex solution.

The MTE II experiment indicates that the ratio between moving and stationary n50 decreases with increasing angular velocity. Table 3 presents the n50's which best represent the experimental results for each angular velocity. The 2/3 rule seems appropriate for the lowest angular velocity but not for the higher angular velocities. The n50 values marked by the asterisks have been adjusted to account for an incomplete spectrum of probabilities. (i.e., 97% of the observed Pd's were less than 0.2 for the 0 mr/sec and 0.6 for the 0.9 mr/sec angular velocities.)

Table 3 n50's

Angular Velocity	n50	n50 Ratio (moving/stationary)
0.0 mr/sec	5.7*	1
0.9 mr/sec	4.1*	0.72
2.3 mr/sec	2.5	0.42
3.7 mr/sec	1.9	0.33

Figure 5 plots the n50 results for the MTE II experiment along with the results of two previous experiments – MTE I and Summer 94. MTE I was a foveal vision experiment. When present, all targets appeared in the center of the image. No search was involved. The approach to simulating an increase in range was to shrink the image. At

the 1500 m target range the image subtended 6° horizontally, and at 6000 m the image subtended 1.5°. The shrinking images in MTE I had a confounding effect on n50 (n50 decreased with shrinking image). Since the only angular velocities in common between MTE I and II occurred at 1500 m and because of the confounding effects of shrinking images, only the 1500 m MTE I n50's are presented in Figure 5. Further information on MTE I can be found in reference 2.²

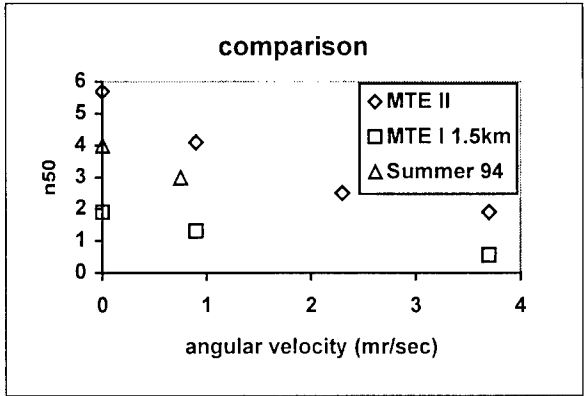


Figure 5 n50 versus velocity and test

The Summer 94 field experiment was the source of the background and target imagery used in both MTE I and MTE II. The moving and stationary target trials were conducted on separate days.

Table 4 provides a comparison of key parameters for the three experiments. The differences in these parameters may explain the wide variability in the resulting n50's. The observers were basically performing different tasks in each of these experiments resulting in different n50's. Reference 3 provides further information on how the n50 for stationary targets varies in relation to such factors as clutter, false targets, sensor resolution, and observer task.

Table 4. Comparison of Test Parameters

	MTE II	MTE I	Summer 94
Search	6° image	6° to 1.5° image	120° sector
Experiment Type	Lab	Lab	Field
Time Limit (seconds)	9	3	60 (moving) 180 (stationary)
Range (km)	0.75-3.0	1.5-6.0	0.5-1.5
Average False Targets per Observer per Trial	0.19	0.16	0.008 (mov) 0.08 (stat)
Average Pd	0.32	0.35	0.60 (mov) 0.47 (stat 60 sec) 0.64 (stat 180 sec)

Even though the resulting n50's were different, the ratios of moving target to stationary target n50 were remarkably similar as illustrated in Figure 6. The ratio decreases as angular velocity increases. The following equation produced the line that fits the data in Figure 6.

Ratio = exp (-0.4 * ang.vel.^{0.85}) (1)

Equation (1) indicates that the current “2/3 ratio rule” equates to an angular velocity of 1.0 mr/sec. However, the ratio reduces to 1/3 at an angular velocity of 3.3 mr/sec. Since a non-zero lower limit on the ratio likely exists, care should be taken when extrapolating equation (1) beyond an angular velocity of 3.7 mr/sec.

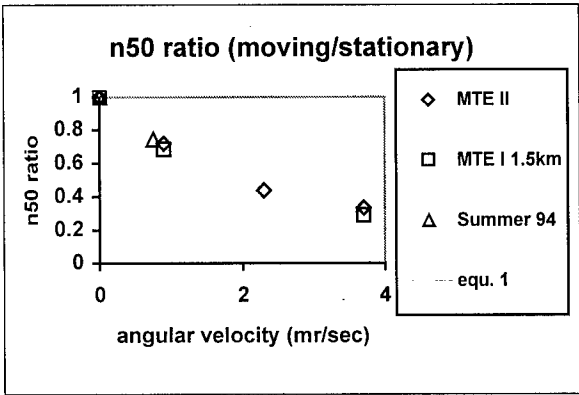


Figure 6 n50 ratios (moving/stationary)

It should be noted that equation (1) has been developed from a limited set of data and may have limited applicability. The experimental data used represents unaided eye performance at target ranges of 3000m or less. Additional experiments are required to investigate the applicability of equation (1) to magnified optics and thermal sensors.

6. FURTHER ANALYSIS

Analysis of the MTE II is ongoing. Additional areas of investigation include: variations in contrast as the target moves (does greater variation lead to higher Pd or faster detection?), time to detect (how does time to detect correlate with the peaks and nulls in contrast and background variations?), background characteristics (what is it about one region of the background that makes a 0.3 target contrast more detectable than in another region of the background of equal range?)

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Scott Schoeb and Lilly Harrington, USAMSAA constructed the experimental stimuli.

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